COMPUTERIZATION OF AIRCRAFT NAVAL AIR TRAINING AND OPERATING PROCEDURES STANDARDIZATION (NATOPS) FLIGHT PERFORMANCE CHARTS

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NAVAL POSTGRADUATE SCHOOL
Monterey, California

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NAVAL AIR TRAINING AND OPERATING
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FLIGHT PERFORMANCE CHARTS

by

Johnny Dean Restivo

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)
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techniques shown in this thesis are applicable to any aircraft, both fixed and rotary wing.

A much improved and more accurate method of mission planning is needed to reduce NATOPS chart errors during pre-flight planning and to reduce the accident potential of air crews who make performance decisions during flight from past experience or old information, without accounting for all variables which affect aircraft performance. A large percentage of Navy/Marine Corps aircraft accidents has been directly or indirectly attributed to misinterpretation of NATOPS charts and/or poor performance decisions. Computerized NATOPS performance charts will significantly reduce human errors inherent to visual chart interpretation and, when coupled with aircrews having computer access to make airborne aircraft performance decisions based on all performance variables, will greatly enhance safety of flight in completing any or all mission phases, thereby increasing operational readiness of all Navy/Marine Corps fleet units.

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I. INTRODUCTION

The objective of this thesis was to investigate the feasibility of computerizing aircraft Naval Air Training and Operating Procedures Standardization Program (NATOPS) flight performance charts with a high degree of accuracy and to develop computer programs which are adaptable to hand-held calculators, desk calculators, or existing internal aircraft systems computers. The NATOPS performance charts of operational aircraft used in the Navy and Marine Corps are a conglomeration of graphs, charts, curves, and tables which are frequently cumbersome and very susceptible to user error in their interpretation and manipulation. The charts present performance information for all aspects of flight operations, from take-off to final landing. Therefore, it is imperative that flight crews be able to interpret and utilize these charts to obtain optimum and efficient performance from their respective aircraft in all phases of the specified mission.

Mission planning is an essential and key element of flight operations and must insure a high degree of safety and maximum utilization of the aircraft performance in order to successfully accomplish the mission. This planning requires use of the NATOPS charts to determine take-off distances, climb profiles, cruise distances, low-level distances and fuel used in all mission phases. Such mission planning is very time consuming and very susceptible to error since it requires

eye-ball interpolation between curves which are as wide as the user's pencil lead, and various information is transferred from chart to chart. For example, even with extremely precise and careful interpretation of take-off distance, an error of ± 200 feet could be made due to pencil width alone, exclusive of interpolative errors. The combination of these human and mechanical errors could build to as much as 500 feet, which would be very critical when taking off at maximum gross weight on a hot day. Errors in fuel management would be equally as critical, if the mission profile dictated return to base or ship with minimal fuel. Also, it is noted that utilization of the NATOPS performance charts is generally limited to pre-flight planning and not feasible for use in high performance aircraft, and in several of the helicopters, for in-flight changes in mission profile. A NATOPS pocket check list is used for in-flight planning, which is small and therefore subject to even higher human and mechanical interpolation errors.

Therefore, a much improved and more accurate method of mission planning, both before flight and during flight, is needed. A desk top calculator or hand-held computer with pre-programmed chips could eliminate these errors during pre-flight planning, while in-flight errors could be reduced substantially with performance equations programmed into an on-board systems computer of the aircraft, or a hand-held computer with a dedicated or read only memory (ROM), a program chip, capable of storing performance equations for all

mission phases. Not only would computerization reduce the human errors of flight crews who have the NATOPS charts available, it would reduce the accident potential of flight crews who are airborne without NATOPS and make performance decisions from past experience. Such decisions, without accounting for all variables which affect aircraft performance, could lead to large errors in predicting the capability of the aircraft to safely complete a mission phase; and have been cited as the cause of a large percentage of Navy/Marine Corps accidents in both fixed and rotary wing aircraft. Computerization would also greatly enhance shipboard operations by providing instance Bingo (minimum fuel) profiles to both flight crews and the air base, reducing fuel management errors based on experience and interpolation of charts.

This thesis computerizes A-6E aircraft NATOPS take-off and cruise performance charts [Ref. 1]. However, the feasibility, procedures and techniques are applicable to any aircraft, both fixed and rotary wing. The feasibility aspect of the thesis is a continuing application of thesis research conducted for computerization of A-7E performance [Ref. 2]. The programs are written in BASIC language for the Hewlett-Packard 9830A computer, but knowledge of the language is not required to demonstrate the feasibility of accurate performance computerization. The performance equations within the programs can be directly utilized in most scientific computer languages, with easy adaptation to any computer such as hand-held, desk top, or aircraft systems computers.

II. EXPERIMENTAL PROCEDURE

A. GENERAL ORGANIZATION

Two separate, but equally important, A-6E aircraft performance charts were evaluated for computerization feasibility. The first chart, "Take-off Performance" [Ref. 1, Fig. 11-11], was utilized since its family of relatively simple, or low order polynomial equations, provided use of basic curves in studying and developing the programming techniques. The second chart, "Cruise Performance," [Ref. 1, Fig. 11-110], provided a more complex family of curves which required more extensive analysis in program development. Empirical data were taken from the specific NATOPS chart and the Least-Squares method of polynomial approximation was used to determine the coefficients of each curve in the respective family of curves. A polynomial expression was then approximated using the same method to determine the family of coefficients. In other words, polynomial expressions were determined which approximated the coefficients of any curve which would fall within the bounds of the respective family of curves. This technique precluded the need for interpolation between curves. A detailed example of the Least Squares method is presented in Appendix A, while Figure 1 presents a simplified example of approximating a family of curves.

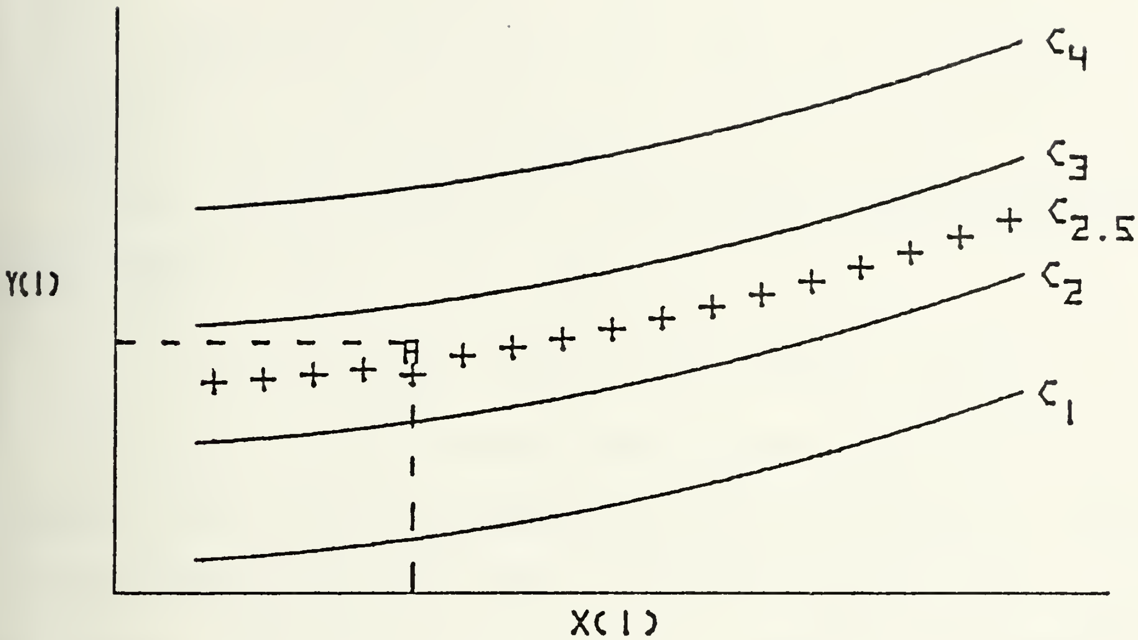


Figure 1. Family of curves.

Least Squares approximations yield polynomial expressions for each curve in the form of

$$Y(1) = a_{10} + a_{11} \cdot x_1 + a_{12} \cdot x_1^2$$

$$Y(2) = a_{20} + a_{21} \cdot x_2 + a_{22} \cdot x_2^2$$

$$Y(3) = a_{30} + a_{31} \cdot x_3 + a_{32} \cdot x_3^2$$

$$Y(4) = a_{40} + a_{41} \cdot x_4 + a_{42} \cdot x_4^2$$

where for $a_{i,j} \cdot x_i$, i is the specific curve and j is the coefficient subscript.

A polynomial expression for each coefficient family is determined in the form of:

$$A(0) = b_o + b_1 \cdot C + b_2 \cdot C^2$$

$$A(1) = b_o + b_1 \cdot C + b_2 \cdot C^2$$

$$A(2) = b_o + b_1 \cdot C + b_2 \cdot C^2$$

where "C" is the curve variable.

Then, the expression for the curve passing through point A in Figure 1 for $X_i = C_{2.5}$ is:

$$Y(2.5) = A(o) + A(1) \cdot X_{2.5} + A(2) \cdot X_{2.5}^2.$$

The Least Squares method was programmed for the Hewlett-Packard 9830A computer complemented with the Hewlett-Packard 9266A plotter which was used to verify that the plot of the polynomial expressions did, in fact, duplicate the specific NATOPS curve. The accuracy of the polynomial approximations was determined by evaluating the percentage of deviation of the approximated curve at specific points from the same points on the actual NATOPS curve. It was possible to achieve greater than ninety-seven percent (97%) overall accuracy.

Accuracy of the polynomial expressions for each coefficient family was determined by comparing the computed value of the coefficient evaluated at each curve of the family with the original coefficient approximated for each curve. A more detailed description of the computer techniques is contained in Ref. [2].

B. TAKE-OFF PERFORMANCE

The A-6E aircraft NATOPS normal take-off performance chart [Fig. 3] was photographed and enlarged five times its original size to allow more accurate measurement of empirical data.

The chart was then separated into sub-charts composed of families of curves for individual evaluation of computerization feasibility. The dependent variable or output of the first sub-chart became the independent variable or input of the succeeding sub-chart. Table I shows the relationship of sub-charts to the independent and dependent variables.

TABLE I

TAKE-OFF PERFORMANCE SUB-CHARTS

Sub-Chart	Family of Curves Parameter	Input	Output
I	Pressure Altitude	Temperature	Reference Index
II	Gross Weight	Reference Index	No Wind Take-off Distance
III	Take-off Distance	Wind	Take-off Distance

Empirical data were taken from the respective sub-chart, the coefficient of each curve was determined, and the family of curves was plotted to verify accuracy with the original sub-chart. Once the points verified for each curve were within one percent of the original empirical data, the coefficients of the family of curves were determined. A computer program was written and the coefficients were verified for accuracy within two and one-half (2-1/2) to three (3) percent of the coefficient previously obtained for each curve. The independent variable for the coefficients of the family of curves is the specific "family of curves parameter," such as

pressure altitude in Sub-Chart I. The dependent variables are the coefficients of the curve passing through the specific family of curves parameter. These coefficients are then used in the output equation of the specific sub-chart.

In Sub-Chart I, "Pressure Altitude," it was relatively simple to determine the coefficients of the family of curves, since there were the same linear relationships between each curve. But Sub-Charts II and III, "Gross Weight" and "Take-off Distance with Wind," had to be broken down into three and two sub-families of curves, respectively. This was required since the non-linear relationship between curves would produce inaccurate coefficients for the family of curves. By overlapping smaller sub-families of curves whose relationships were more linear, the desired accuracy could be achieved. The range covered by each sub-family of curves was determined by trial and error iteration until the desired accuracy was achieved. Coefficients for the sub-family of curves would then be used in the output equation for the specific sub-chart. The sub-family coefficients used depend upon the range in which the desired family of curve parameter would lie. The computer program was written to check for the limits of each sub-family range.

Once satisfactory programs were written for each sub-chart, they were integrated into one computer program which would yield a final output of take-off distance with wind. The final program also includes equations which calculate take-off velocity, and unsafe and not-recommended take-off distances.

The coefficients for these equations were determined in the same manner as individual curves for the sub-charts. A wind component computation using basic trigonometry identies was used to input winds into Sub-Chart III, and a round-off routine was used prior to the final output printout. The round-off criterion established for take-off velocity was one-half (0.5) knots, while that for take-off distance was twenty-five (25) feet. Twenty-five feet was used for take-off distance round-off, since at high take-off velocities this value would be negligible in rounding down, but would still provide a factor of safety for round-up to the nearest one hundred (100) feet.

C. CRUISE PERFORMANCE

The A-6E NATOPS Cruise Performance Charts are a series of separate charts or four phases which require that the output of each chart be transferred as the input to the succeeding chart until arriving at the final output of "fuel flow." These four phases are:

Phase I	Clean Aircraft Transfer Scale
Phase II	Aircraft Reference Number
Phase III	Pounds of Fuel per Nautical Mile
Phase IV	Fuel Flow

Since Phase I chart consisted of the most non-linear curves, in contrast to the linear curves of Phases II, III and IV, and in view of project time constraints, only Phase I was evaluated for computerization feasibility. This chart

was also photographed and enlarged to facilitate extraction of accurate empirical data. As in take-off performance, the chart was separated into sub-charts for individual evaluation of families of curves. This technique varied from that of take-off performance in that Sub-Chart II had an overlying family of curves which had to be treated as separate entities. The dependent variable or output of one curve family became an independent variable or input to the second curve family. Table II presents the sub-charts with respective curve families and variables.

TABLE II

PHASE I CRUISE PERFORMANCE SUB-CHARTS

Sub-Chart	Family of Curves Parameter	Input	Output
I	Pressure Altitude	Gross Weight	Mach
II	Guideline	Mach	Transfer Scale
III	Drag Count	Transfer Scale	Mach

Determination of the coefficients of each curve, accuracy verification, and determination of curve family coefficients were accomplished using the same method described in Take-off Performance. Sub-Chart I, "Pressure Altitude," and Sub-Chart II, "Guideline," had to be broken down into two overlapping sub-families of curves to achieve the desired accuracy. The range of each sub-family was determined by trial and error until the desired accuracy was achieved. Coefficients for

each family of curves were used in the output equation for the computer program written for each family of curves. Each program with sub-families was checked for the range in which the family of curves parameter would lie to ensure that the proper coefficients were utilized.

Since Sub-Chart II had overlying curve families, which required that the input variable, Mach number, would intercept a guideline at the zero drag count, and proceed down that line until intersecting the desired drag count line, a comparing and decrementing routine had to be developed. A graphical example of this routine is shown in Figure 2.

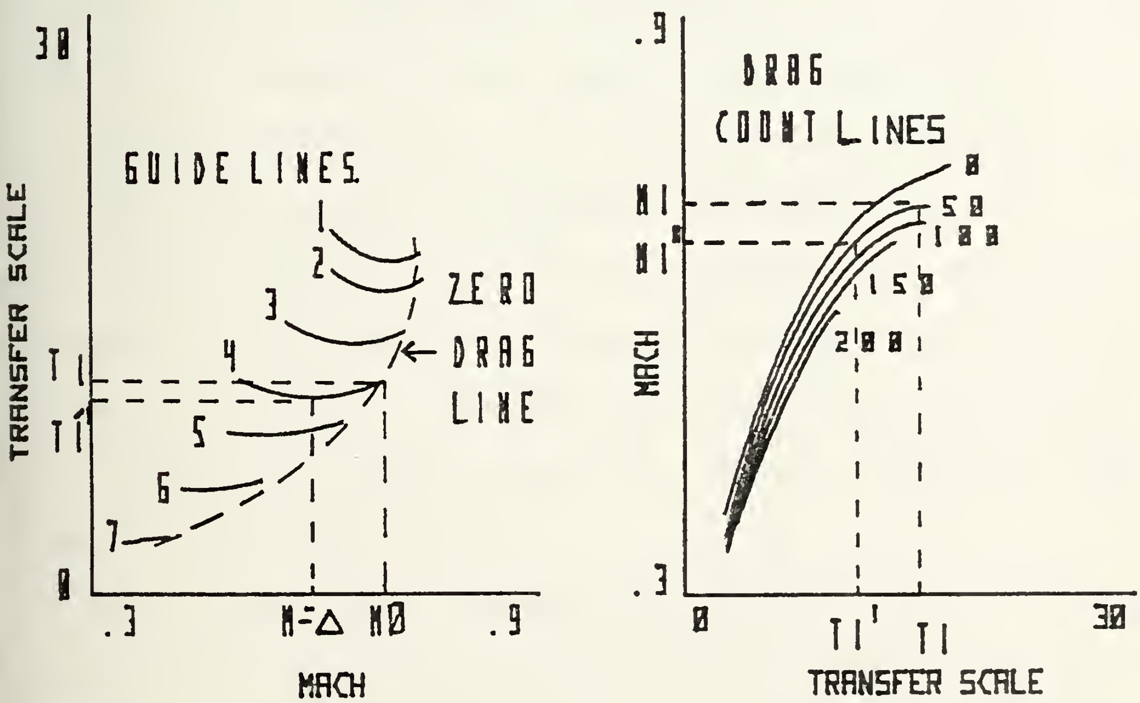


Figure 2. Mach comparison and decremation.

In this routine, initial Mach (MØ) from Sub-Chart I is input, as the independent variable, into the zero drag count equation which outputs the dependent variable, initial transfer scale (TØ). TØ then becomes the independent variable which determines the specific guideline to be used by establishing its coefficients. The independent variable in the guideline equation is Mach, which calculates the dependent variable, Transfer Scale (T1). T1 is then input as the independent variable into the selected drag count equation which calculates the dependent variable, Mach (M1). M1 is then compared to the previous Mach which was input to the guideline equation. For the first iteration, M1 is compared with MØ. If the absolute value of the difference between the two Machs is not less than or equal to 0.01, then MØ is decremented, $\Delta = .01$, and a new transfer scale, T1', is calculated and input back into the drag equation to output's new Mach, M1'. This iterative and comparison routine is continued until the comparison parameter is satisfied. The compared Machs are then averaged and output as Best Cruise Mach, M2, while the last computed T1 is output as Transfer Scale, T. M2 and T are the final outputs of Sub-Chart II.

Once satisfactory programs were written for each sub-chart and verified for accuracy, they were integrated into one computer program to yield the final output of Best Cruise Mach and Transfer Scale. The numerical values of these outputs were not rounded off for aircrew use, since they would be

transferred as inputs to subsequent phase charts of the cruise performance computer program in follow-on thesis work.

III. RESULTS AND DISCUSSION

A. TAKE-OFF PERFORMANCE

The A-6E NATOPS normal take-off performance chart, Figure 3, was used to study the feasibility and to expand the basic techniques of computerizing NATOPS charts. As previously discussed, each sub-chart was evaluated separately and then integrated into one computer program. However, Sub-Chart IV, Obstacle Clearance, was not utilized in the program since this aspect of take-off is seldom critical for the A-6E aircraft. Each sub-chart family of curves was relatively simple to reproduce using the Least Squares method since the highest order of polynomial equation approximated was third order. The accuracy of each reproduced curve was verified to be greater than ninety-nine percent (99%). A comparison of Sub-Chart II, Gross Weight, of Figure 3 with that plotted from the approximated equations, Figure 4, will show that an almost exact reproduction of the NATOPS charts can be made by Least Squares approximations. The ordinate system of Figure 4 is transposed relative to that in Figure 3, since the output variable of Sub-Chart I is the input variable to Sub-Chart II.

While the individual curves of each respective sub-chart could be reproduced with a high degree of accuracy, high errors were generated when approximating coefficients for the family of curves in Sub-Charts II and III. These errors were a direct result of the curves in Sub-Chart II becoming more

TAKE-OFF DISTANCE (normal)

P-8 ENGINE

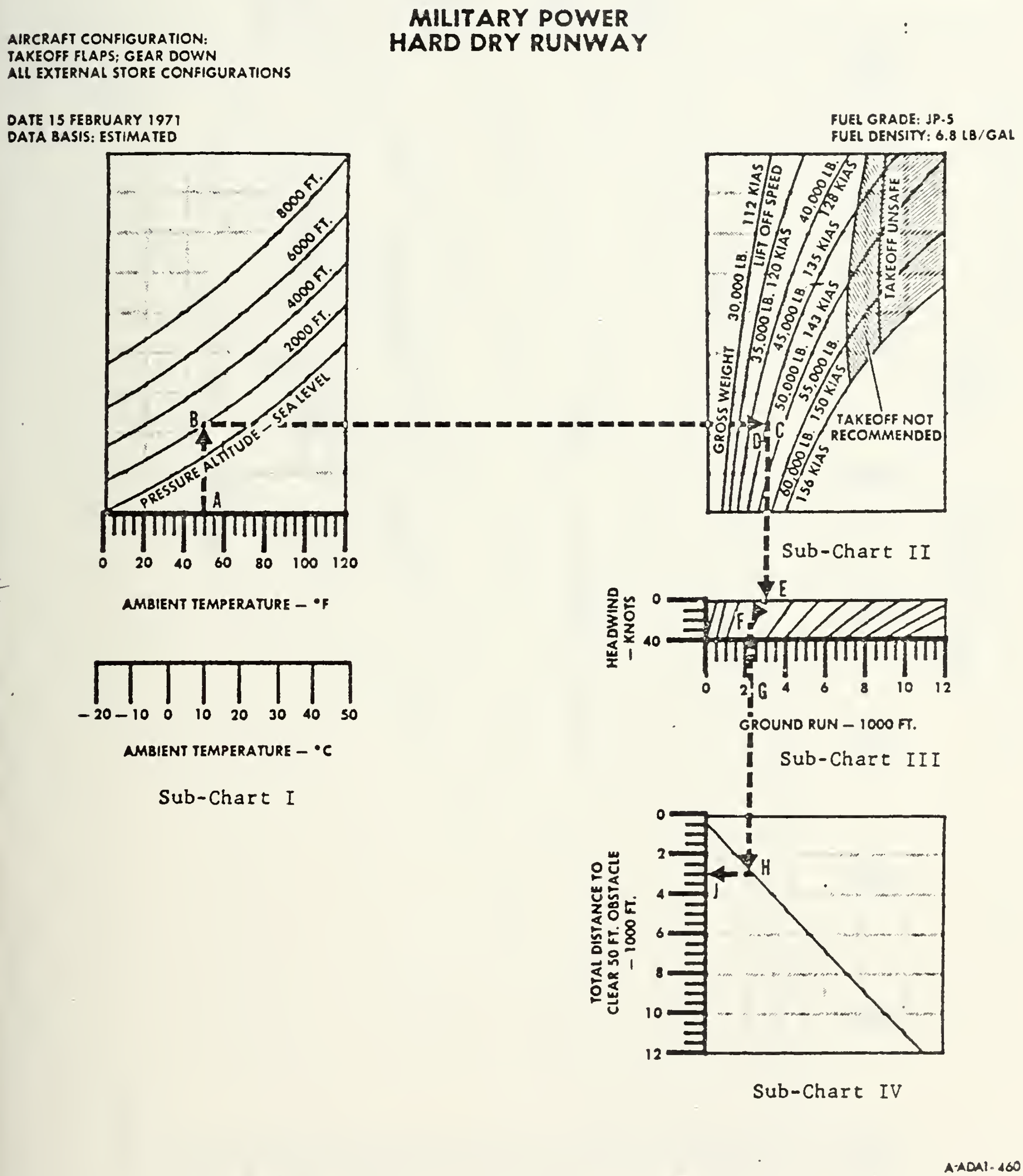


Figure 3. A-6E Normal Take-off Distance.

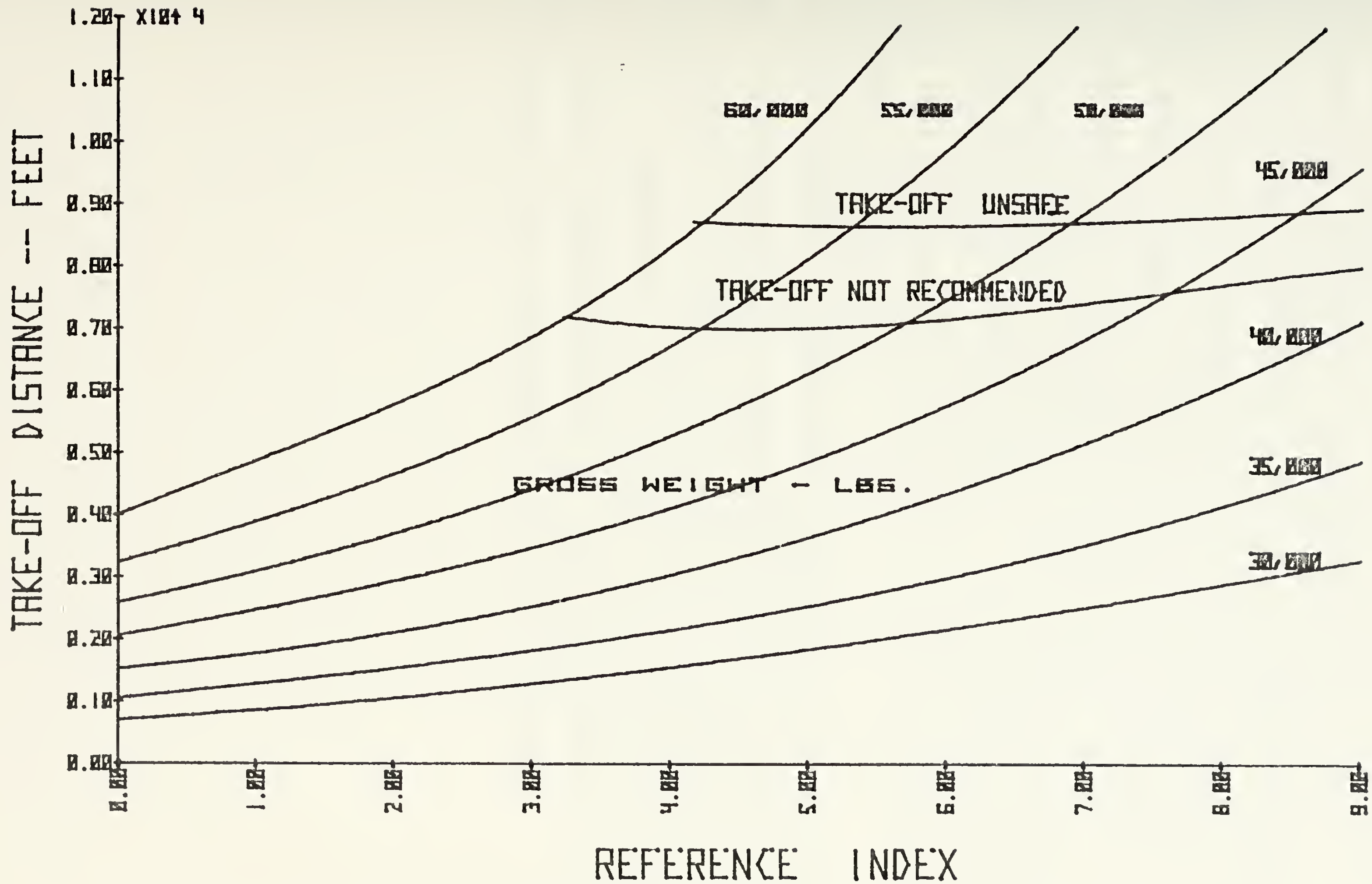


Figure 4. Take-off Sub-Chart II Approximated Curves.

non-linear as the gross weight increased, and of the large slope changes in Sub-Chart III curves as the take-off distances increased. The errors in these sub-charts were reduced to less than two percent (2%) by overlapping smaller sub-families of curves of more nearly the same linearity and slope. The gross weights were reduced to an overlapping family of curves reflecting gross weight changes of ten thousand (10,000) pounds, while take-off distance was overlapped at the mid-curve of the family. The specific overlap points were determined by trial and error until an acceptable error tolerance was achieved.

The final computer program which culminated the respective sub-chart programs into one A-6E NATOPS take-off performance computer program is included in Appendix B. Sample program results are in Appendix E, while Table III shows the relative accuracy between computer and manual chart determinations of take-off distances for representative input parameters.

TABLE III

TAKE-OFF DISTANCE ACCURACY

	1	2	3	4
Gross Weight (lbs.)	34,000	40,000	48,000	53,000
Pressure Altitude (ft.)	0	1,000	5,000	0
Temperature, Deg. (F)	60	100	60	80
Runway Heading, Deg.	360	360	360	360
Wind Direction, Deg.	360	318	042	060
Wind Velocity	10	20	20	20
Headwind Velocity	10	15	15	10
Take-off Distance:				
Manual Chart	1,200	2,550	4,400	4,400
Computer	1,200	2,500	4,300	4,400
Accuracy (%)	100	98	97	100

B. CRUISE PERFORMANCE

The A-6E NATOPS Cruise Performance Chart - Phase I is shown in Figure 5, while all four phase charts are included in Appendix C. The same basic tachniques used in take-off performance were applied to cruise performance with exception of the iterative routine required for the overlying drag count and guideline curves of Sub-Chart II. As in take-off performance, Sub-Chart I, pressure altitude curve family, was relatively easy to reproduce with individual curve accuracies verified as greater than ninety-nine percent (99%).

CRUISE PERFORMANCE

P-8 ENGINE

PHASE I – CLEAN AIRCRAFT TRANSFER SCALE

DATE 15 MARCH 1971
DATA BASIS: ESTIMATED

FUEL GRADE: JP-5
FUEL DENSITY: 6.8 LB./GAL.

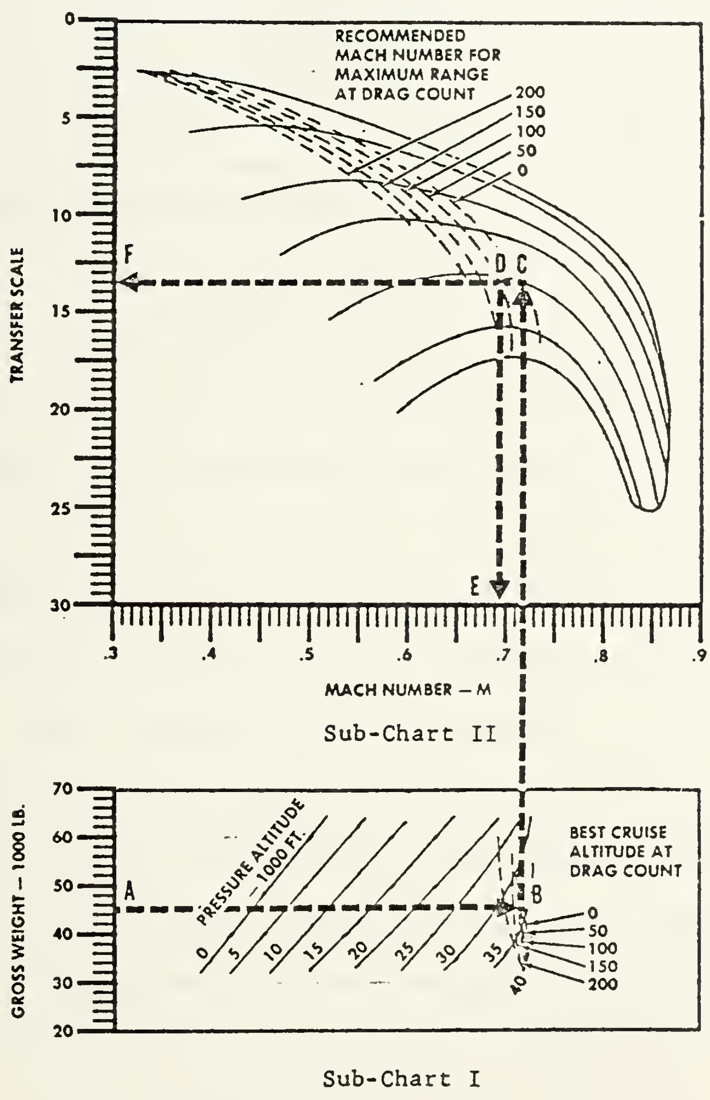


Figure 5. Cruise Performance, Phase I.

However, high errors were generated when approximating coefficients for the curve family due to the increased non-linearity as pressure altitude increased. These high errors were reduced to less than two percent (2%) by overlapping sub-families of curves from zero (Ø) to thirty thousand (30,000) feet and thirty (30) to forty thousand (40,000) feet.

In order to achieve accuracies of greater than ninety-nine percent (99%) for the individual curves of the drag count family in Sub-Chart II, a high number of empirical data points were used and the approximated coefficients were limited to fourth order. This was required to smooth the curves out and prevent oscillations between points. In addition, some points in the zero (Ø) drag count curve were adjusted slightly to add additional curve smoothing and better curve reproduction. While adjustments were necessary to achieve individual curve accuracy, none was required to approximate coefficients for the entire family of drag curves, which resulted in greater than ninety-eight percent (98%) accuracy.

Due to the extreme non-linearities of the guideline family of Sub-Chart II, the individual curve approximations were limited to the range that overlaid only the drag count curves. This restriction was required to achieve greater than ninety-nine percent (99%) individual curve accuracy, and to limit the overlapping sub-family of curves to two. The sub-families overlapped at the fourth guideline, as counted from bottom to top in Figure 4.

Since the Hewlett-Packard 9830 Computer Plotting Routine requires that the X and Y axis increase from the ordinate, the transfer scale of Sub-Chart II, Figure 4, had to be inverted to reflect values from zero to thirty, vice thirty to zero. This inversion of the Y-axis caused the approximated guideline curves to be plotted inverted, Figure 2. However, this did not affect the output, transfer scale, since the initial point of entry into the guideline curve family is only dependent upon the initial transfer scale, which is derived from the zero drag count equation regardless of curve orientation. Also, as discussed previously, the iterative routine required that the approximated drag count family of curves be transposed, Figure 2, so that Best Cruise Mach could be determined by comparing input Mach to the guidelines and output Mach from the drag counts. An attempt was made to keep the drag count curves oriented the same as the guideline curves, but the program would not step out of its iterative routine when the input Mach would not pass through the desired drag count curve when intercepting the zero drag count curve. For example, as depicted in Figure 4, an input Mach of 0.73 does not pass through a desired drag count of fifty (50).

The final computer program which culminated the respective sub-chart programs into one A-6E NATOPS Cruise Performance Phase I computer program is included in Appendix D. Sample Program results are in Appendix E, while Table IV shows the relative accuracy between computer and manual chart determinations of transfer scale and best cruise Mach for representative input parameters.

TABLE IV

PHASE I CRUISE PERFORMANCE ACCURACY

	1	2	3	4
Pressure Altitude (ft.)	33,000	25,000	15,000	37,000
Gross Weight (lbs.)	48,000	50,000	58,000	42,000
Drag Count	20	100	150	20
Best Cruise Mach				
Manual	.710	.620	.559	.718
Computer	.714	.623	.557	.722
Accuracy (%)	99.4	99.5	99.6	99.4
Transfer Scale				
Manual	13.75	9.8	7.8	14.4
Computer	13.65	9.9	7.9	14.5
Accuracy (%)	99.2	99.	98.7	99.3

IV. CONCLUSIONS AND RECOMMENDATIONS

Within the scope of this thesis project, computerization of aircraft Naval Air Training and Operating Procedures Standardization Program (NATOPS) flight performance charts has been shown to be feasible with a high degree of accuracy. The computer programs developed for the A-6E aircraft are adaptable to hand-held calculators, desk calculators, or the existing aircraft systems computer. The feasibility, procedures, and techniques discussed are applicable to any aircraft, fixed or rotary wing. Utilization of computerized NATOPS performance charts for before-flight and during-flight mission planning will significantly reduce the human and mechanical errors inherent to visual interpretation and interpolation of the charts.

This reduction in chart errors, when coupled with aircrews having computer access to make airborne aircraft performance decisions based on all performance variables, rather than on past experience only, will greatly enhance safety of flight in completing any or all mission phases. By enhancing safety of flight through NATOPS performance chart computerization which is accessible to all flight crews, the operational readiness of all Navy/Marine Corps fleet units will be increased.

Development of NATOPS performance charts computer programs should be expanded to encompass all phases of mission planning to include shipboard Bingo (minimum fuel) profiles and tactical

weapons delivery. These computer programs could be incorporated into hand-held calculators with dedicated read only memory (ROM) for use in ready rooms and in aircraft without on-board systems computers, such as most helicopters and light attack fixed wing aircraft; into desk top computers, capable of utilizing cassette tapes to program performance equations for all operational Navy/Marine Corps aircraft for use in land and ship base operations; and into existing on-board system computers, for such aircraft which have the capacity for computer software expansion.

Manual inputs to performance equations incorporated within on-board systems computers could be significantly reduced by utilizing signals from air data computers for temperature, pressure altitude, and velocity inputs; fuel quantity, sensors for gross weight inputs; inertial platforms for angle inputs such as angle of attack, climb angles and glide paths; and weapons selection tapes for drag count inputs.

Future thesis research should address the interface of existing aircraft sub-system output signals as input signals to NATOPS performance chart equations incorporated into on-board aircraft systems computers.

APPENDIX A

LEAST SQUARES METHOD OF POLYNOMIAL APPROXIMATION

The Least Squares method of polynomial approximation is described in detail in reference [3]. Since data points are subject to experimental errors which may be relatively large in magnitude, the best curve fit through these points is one which minimizes the errors. The Least Squares method of approximation minimizes the maximum errors between the data points and the curve by making the sum of the squares of the errors a minimum. The errors are measured by the vertical and horizontal distances from the points to the line as depicted in Figure 6.

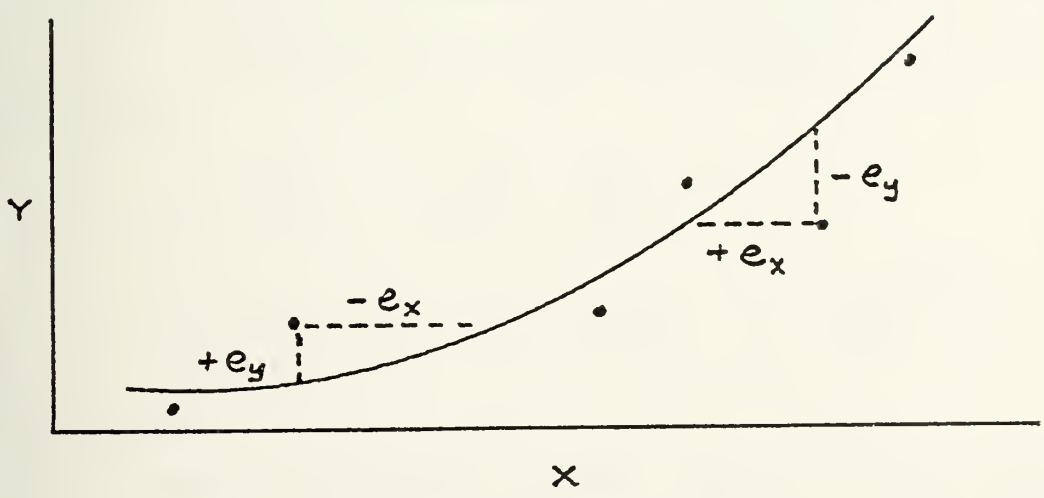


Figure 6. Error Measurement.

The sum of the squares of the errors is used since the function has no derivative at the origin and this could be a single large error. The Least Squares method is also in accord

with the maximum likelihood principle of statistics. If the measurement errors have a normal distribution and if the standard deviation is constant for all the data, the sum of the squares can be shown to have values of slope and intercept which have a maximum likelihood of occurrence.

In the development of an n^{th} degree polynomial which will represent the best curve fit through empirical data, n+1 or greater pairs of data points are required. Let N represent the number of (x,y) data pairs. The functional relationship

$$y = a_o + a_1 x + a_2 x^2 + \dots + a_n x^n \tag{1}$$

is assumed with errors defined by:

$$e_i = Y_i - y_i = Y_i - a_o - a_1 x_i - a_2 x_i^2 - \dots - a_n x_i^n . \tag{2}$$

The Y_i is used to represent the empirical value corresponding to x_i of the data pair. The Least Squares criterion requires that

$$S = e_1^2 + e_2^2 + \dots e_N^2 = \sum_{i=1}^{N} e_i^2$$

$$= \sum_{i=1}^{N} (Y_i - a_o - a_1 x_i - a_2 x_i^2 - \dots - a_n x_i^n)^2 \tag{3}$$

be a minimum.

The minimum is reached by proper choice of the coefficients, a_o through a_n. Therefore, the coefficients are the variables of the problem. At the minimum for S, the partial derivatives of S with respect to the coefficients are zero. Writing the equations for the n+1 derivative equation give:

$$\partial S/\partial a_o = 0 = \sum_{i=1}^{N} 2(Y_i - a_o - a_1x_i - \ldots - a_nx_i^n)(-1),$$

$$\partial S/\partial a_1 = 0 = \sum_{i-1}^{N} 2(Y_i - a_o - a_1x_i - \ldots - a_nx_i^n)(-x_i),$$

$$\vdots \qquad\qquad\qquad\qquad \vdots \qquad (4)$$

$$\partial S/\partial a_n = 0 = \sum_{i=1}^{N} 2(Y_i - a_o - a_1x_i - \ldots - a_nx_i^n)(-x_i^n).$$

Dividing each of these equations by -2 and rearranging gives the n+1 normal equations to be solved simultaneously:

$$a_oN + a_1\Sigma x_i + a_2\Sigma x_i^2 + \ldots + a_n\Sigma x_i^n = \Sigma Y_i,$$

$$a_o\Sigma x_i + a_1\Sigma x_i^2 + a_2\Sigma x_i^3 + \ldots + a_n\Sigma x_i^{n+1} = \Sigma x_iY_i,$$

$$a_o\Sigma x_i^2 + a_1\Sigma x_i^3 + a_2\Sigma x_i^4 + \ldots + a_n\Sigma x_i^{n+2} = \Sigma x_i^2 Y_i,$$

$$\vdots \qquad\qquad\qquad\qquad \vdots \quad (5)$$

$$a_o\Sigma x_i^n + a_1\Sigma x_i^{n+1} + a_2\Sigma x_i^{n+2} + \ldots + a_n\Sigma x_i^{2n} = \Sigma x_i^n Y_i.$$

All the summations run from 1 to N.

Numerical methods are used to solve these equations simultaneously and are discussed in detail in reference [3]. These particular equations have an added difficulty in that they have the undesirable property known as "ill-conditioning." The result is that round-off errors in solving them cause unusually large errors in the solutions, which are the desired values of the coefficients, a_i's. Up to n=4 or 5 the problem is not too great, but beyond this point special orthogonal polynomial

methods are needed, which is a separate topic in reference [3]. However, from the experimental point of view, functions more complex than fourth-degree are rarely needed, and when they are, the problem can often be handled by fitting a series of polynomials to subsets of data.

To illustrate the use of equation (5), a quadratic is fit to the data of Table V.

TABLE V

CURVE FIT DATA

Data Pairs

x_i	0.0	0.2	0.4	0.7	0.9	1.0
Y_i	1.016	0.768	0.648	0.401	0.272	0.193

Summations for N=6

x_i	x_i^2	x_i^3	x_i^4	Y_i	$x_i Y_i$	$x_i^2 Y_i$
3.2	2.5	2.144	1.9234	3.298	1.1313	0.74421

The data are actually a perturbation of the relationship

$$y = 1 - x + 0.2\, x^2 \tag{6}$$

The curve of equation (6) and the perturbated data are shown in Figure 7.

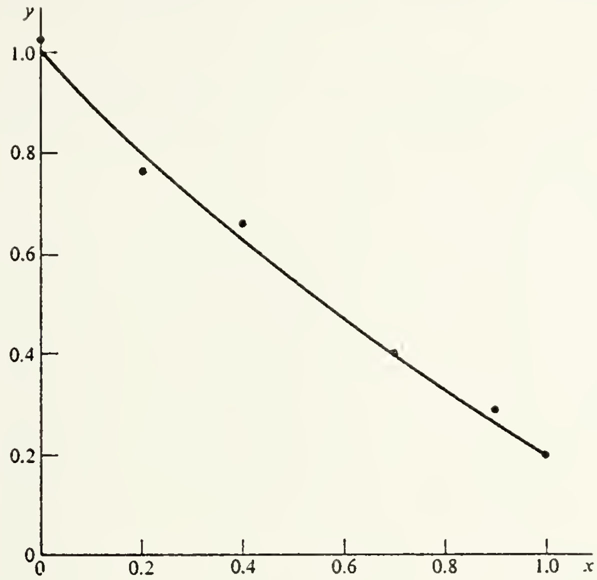


Figure 7. Curve fit data plot.

The summations tabulated in Table V are substituted into equations (5) to give the following set of equations:

$$\begin{aligned} 6\ a_o + 3.2\ a_1 + 2{,}5\ a_2 &= 3.298, \\ 3.2\ a_o + 2.5\ a_1 + 2{,}144\ a_2 &= 1.1313, \\ 2.5\ a_o + 2.144\ a_1 + 1.9234\ a_2 &= 0.74421. \end{aligned} \tag{7}$$

Using numerical methods of solution to simultaneous equations yield:

$$a_o = 0.9986,\ a_1 = -1.0060,\ a_2 = 0.2103.$$

Therefore, the equation of the Least Squares approximated polynomial through the data of Table V is:

$$y = 0.999 - 1.006\ x + 0.210\ X^2 \tag{8}$$

The coefficient of equation (8) is slightly different from that of equation (6) because of the errors in the empirical data.

APPENDIX B

TAKE-OFF PERFORMANCE COMPUTER PROGRAM

```
20 PRINT "*                                                                  *"
30 PRINT "*          A-6E NATOPS TAKE-OFF PERFORMANCE COMPUTER PROGRAM        *"
40 PRINT "*                                                                  *"
50 PRINT "*                      NORMAL TAKE-OFF DISTANCE                    *"
60 PRINT "*                                                                  *"
70 PRINT "*     MAJOR J.D.RESTIVO, USMC          NAVAL POSTGRADUATE SCHOOL   *"
80 PRINT "*                                              JUNE 1978           *"
90 PRINT "********************************************************************"
100 PRINT
110 PRINT
120 PRINT "THE A-6E NATOPS NORMAL TAKE-OFF PERFORMANCE CHART IS COMPOSED"
130 PRINT "OF FOUR SUB-CHARTS. EACH SUB-CHART TRANSFERS ITS RESPECTIVE OUTPUT"
140 PRINT "AS INPUT TO THE NEXT SUB-CHART IN SEQUENCE.  THESE SUB-CHARTS ARE:"
150 PRINT
160 PRINT "  SUB-CHART       CURVE FAMILY           INPUT             OUTPUT"
170 PRINT " -----------    --------------         --------.         ---------"
180 PRINT
190 PRINT "      I         PRESSURE ALTITUDE    TEMPERATURE     REFERENCE INDEX"
200 PRINT "      II          GROSS WEIGHT     REFERENCE INDEX   T/O DISTANCE"
210 PRINT "      III         T/O DISTANCE           WIND        T/O DISTANCE"
220 PRINT "      IV        OBSTACLE CLEARANCE   T/O DISTANCE    T/O DISTANCE"
230 PRINT
240 PRINT
250 PRINT "THIS PROGRAM DOES NOT UTILIZE SUB-CHART IV SINCE OBSTACLE "
260 PRINT "CLEARANCE IS SELDOM A CRITICAL CONSIDERATION FOR A-6E TAKE-OFF"
270 PRINT "PERFORMANCE.  THE AIRCRAFT CONFIGURATION FOR NATOPS CHART USED IS"
280 PRINT "WITH THE J52-P8 ENGINE INSTALLED,TAKE-OFF FLAPS,GEAR DOWN,AND"
290 PRINT "ALL EXTERNAL STORE CONFIGURATIONS."
300 PRINT
310 PRINT "THE FINAL OUTPUT PRINTOUT OF THE PROGRAM GIVES INPUT PARAMETERS,WIND"
320 PRINT "COMPONENTS,TAKE-OFF DISTANCES,AND TAKE-OFF VELOCITY.  THE WINDS,"
330 PRINT "DISTANCES,AND VELOCITIES ARE ROUNDED-OFF FOR AIR-CREW COCKPIT USE."
340 PRINT
350 PRINT "THE TAKE-OFF VELOCITY AND WIND USE .5 KNOT AS THE ROUND-OFF"
360 PRINT "CRITERIA, WHILE TAKE-OFF DISTANCE ROUND-OFF IS 25 FEET OR GREATER."
370 PRINT "FOR EXAMPLE, A T/O DISTANCE OF 4240 FT. WOULD ROUND UP TO 4300 FT."
380 PRINT "WHILE A T/O DISTANCE OF 4220 FT. WOULD BE ROUNDED DOWN TO 4200 FT."
```

```
390 PRINT
400 PRINT "THIS PROVIDES A MARGIN OF SAFETY BY ROUNDING UP TAKE-OFF DISTANCES"
410 PRINT "TO THE NEXT 100 FEET, WHILE PRECLUDING ROUND-UP OF NEGLIGIBLE OR"
420 PRINT "NON-PERCEIVABLE DISTANCES AT HIGH TAKE-OFF VELOCITIES"
430 PRINT
440 PRINT "A LEGEND IS PROVIDED TO ASSIST IN INTERPRETATION OF THE PROGRAM"
450 PRINT "VARIABLES AND CALCULATIONS.  EQUATION COEFFICIENTS AND COMPUTED"
460 PRINT "ARE INCLUDED FOR VERIFICATION AND SUBSEQUENT PROGRAM EXSPANSION"
470 PRINT
480 PRINT "---------------------------------------------------------------------
490 PRINT
500 PRINT
510 PRINT "                         **** LEGEND ****"
520 PRINT
530 PRINT "          *INPUT VARIABLES*                 *OUTPUT VARIABLES*"
540 PRINT "         -------------------               --------------------"
550 PRINT
560 PRINT "    A = TAKE-OFF GROSS WEIGHT          I = HEADWIND/TAILWIND COMPONENT"
570 PRINT "    B = RUNWAY PRESSURE ALTITUDE       J = CROSSWIND COMPONENT"
580 PRINT "    C = RUNWAY TEMPERATURE,DEG.(F)     E = NO WIND TAKEOFF DISTANCE"
590 PRINT "    R = RUNWAY HEADING,MAG.DEG.        K = TAKEOFF DISTANCE WITH WIND"
600 PRINT "    W = RUNWAY WINDS,MAG.DEG.          L = TAKEOFF VELOCITY,KNOTS"
610 PRINT "    S = RUNWAY WIND VELOCITY,KTS.      F = TAKEOFF UNSAFE DISTANCE"
620 PRINT "---------------------------------------------------------------------
630 PRINT "                                       G = T/O NOT RECOMMENDED DISTANCE"
640 PRINT
650 PRINT "                      *EQUATION COEFFIECIENTS*"
660 PRINT "                     --------------------------"
670 PRINT "            A0,A,A2     = PRESSURE ALTITUDE"
680 PRINT "            B0,B1,B2,B3 = GROSS WEIGHT"
690 PRINT "            C0,C1,C2    = TAKEOFF DISTANCE WITH WIND"
700 PRINT
710 PRINT "                   *ACTUAL CALCULATED VARIABLES*"
720 PRINT "                  ------------------------------"
730 PRINT
740 PRINT "            D = REFERENCE INDEX FROM SUB-CHART I TO II"
750 PRINT "            H = ANGLE BETWEEN RUNWAY AND WIND HEADINGS"
760 PRINT "           Q1 = TAKEOFF VELOCITY"
```

```
770 PRINT "                    Q2 = HEADWIND/TAILWIND COMPONENT"
780 PRINT "                    Q3 = CROSSWIND COMPONENT"
790 PRINT "                    Q4 = NO WIND TAKEOFF DISTANCE"
800 PRINT "                    Q5 = TAKEOFF DISTANCE WITH WIND"
810 PRINT "                    Q6 = TAKEOFF UNSAFE DISTANCE"
820 PRINT "                    Q7 = TAKEOFF NOT RECOMMENDED DISTANCE"
830 PRINT
840 PRINT
850 PRINT "-------------------------------------------------------------------
860 PRINT
870 PRINT "NOW INPUT GROSS WEIGHT,PRESSURE ALTITUDE,TEMPERATURE,RUNWAY HEADING,"
880 PRINT "AND WIND DIRECTION & VELOCITY AS REQUESTED BY THE PROGRAM.  THIS"
890 PRINT "PROGRAM IS RESTRICTED TO THE FOLLOWING A-6E NATOPS NORMAL TAKEOFF"
900 PRINT "PERFORMANCE CHART CAPABILITIES:"
910 PRINT
920 PRINT "      GROSS WEIGHT..........  >= 30,000 AND <= 60,000 LBS."
930 PRINT "      PRESSURE ALTITUDE.....  >=      0 AND <= 8,000 FT."
940 PRINT "      AMBIENT TEMPERATURE...  >=      0 AND <= 120 DEG.(F)"
950 PRINT "      HEADWIND COMPONENT....  >=      0 AND <= 40 KTS."
960 PRINT
970 PRINT
980 PRINT "++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++"
990 PRINT "+NOTE--PROGRAM WILL COMPUTE TAILWIND TAKEOFFS IF WIND ANGLE IS > 90+"
1000 PRINT "+AND < 270 DEGREES FROM RUNWAY HEADING. WHILE THESE COMPUTATIONS   +
1010 PRINT "+ARE ACCURATE, TAILWINDS ARE NOT INCLUDED IN THE A-6E NATOPS CHART.+
1020 PRINT "++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
1030 PRINT
1040 PRINT
1050 PRINT "********************************************************************
1060 REM------------------------------------------------------------------
1070 DISP "ENTER TAKEOFF GROSS WEIGHT";
1080 INPUT A
1090 REM
1100 REM------------------------------------------------------------------
1110 REM DETERMINATION OF APPLICABLE GROSS WEIGHT EQUATIONS
1120 REM------------------------------------------------------------------
1130 REM
1140 IF A<30000 OR A>60000 THEN 3260
```

```
1150 IF A >= 30000 AND A<40000 THEN 1210
1160 IF A >= 40000 AND A<50000 THEN 1290
1170 IF A >= 50000 AND A <= 60000 THEN 1370
1180 REM
1190 REM GROSS WEIGHT RANGE: 30000-39999
1200 REM
1210 B0=1.0596E+03-8.24E-02*A+2.3536E-06*A↑2
1220 B1=-2.1829E+03+1.3039E-01*A-1.7646E-06*A↑2
1230 B2=1.0588E+03-6.2092E-02*A+9.1504E-07*A↑2
1240 B3=-8.2061E+01+4.684E-03*A-6.5358E-08*A↑2
1250 GOTO 1460
1260 REM
1270 REM GROSS WEIGHT RANGE: 40000-49999
1280 REM
1290 B0=-2.7058E+03+1.0588E-01*A-4.44E-13*A↑2
1300 B1=-5.4192E+03+2.3267E-01*A-2.299E-06*A↑2
1310 B2=2.0235E+03-8.9056E-02*A+9.862E-07*A↑2
1320 B3=-1.573E+02+6.8812E-03*A-7.3266E-08*A↑2
1330 GOTO 1460
1340 REM
1350 REM GROSS WEIGHT RANGE: 50000-60000
1360 REM
1370 B0=2.5852E+03-1.1754E-01*A+2.352E-06*A↑2
1380 B1=5.9656E+03-2.3778E-01*A+2.556E-06*A↑2
1390 B2=-3.8873E+03+1.52E-01*A-1.4707E-06*A↑2
1400 B3=5.4259E+02-2.1644E-02*A+2.1729E-07*A↑2
1410 REM
1420 REM-----------------------------------------------------------------------
1430 REM  CALCULATION OF REFERENCE INDEX
1440 REM-----------------------------------------------------------------------
1450 REM
1460 DISP "ENTER RUNWAY PRESSURE ALTITUDE";
1470 INPUT B
1480 REM
1490 IF B<0 OR B>8000 THEN 3310
1500 REM
1510 REM
1520 A0=3.45E-04+4.0809E-04*B+1.1358E-08*B↑2-2.5421E-12*B↑3+2.5574E-16*B↑4
```

```
1530 A1=2.5009E-02-1.3981E-06*B-4.286E-10*B↑2+2.5827E-13*B↑3-2.1974E-17*B↑4
1540 A2=8.8172E-05+9.0623E-09*B+6.8321E-12*B↑2-2.6177E-15*B↑3+2.1231E-19*B↑4
1550 REM
1560 DISP "ENTER RUNWAY TEMP. IN DEG. (F)";
1570 INPUT C
1580 REM
1590 IF C<0 OR C>120 THEN 3350
1600 REM
1610 D=A0+A1*C+A2*C↑2
1620 REM
1630 REM------------------------------------------------------------------
1640 REM  CALCULATION OF NO WIND TAKEOFF DISTANCE
1650 REM------------------------------------------------------------------
1660 REM
1670 E=B0+B1*D+B2*D↑2+B3*D↑3
1680 REM
1690 REM------------------------------------------------------------------
1700 REM  ESTABLISH TAKEOFF VELOCITY AND WIND ROUND-OFF CRITERIA
1710 REM------------------------------------------------------------------
1720 REM
1730 R0=0.5
1740 Y=1
1750 REM
1760 REM------------------------------------------------------------------
1770 REM  CALCULATION OF TAKEOFF VELOCITY
1780 REM------------------------------------------------------------------
1790 REM
1800 L=6.8E+01+1.1667E-03*A+1.5E-08*A↑2-1.6667E-13*A↑3
1810 Q1=L
1820 L=FNA(L)
1830 REM
1840 REM------------------------------------------------------------------
1850 REM  COMPUTATION OF WIND COMPONENTS
1860 REM------------------------------------------------------------------
1870 REM
1880 DISP "ENTER R/W HEADING IN DEG. MAG.";
1890 INPUT R
1900 DISP "ENTER WIND DIRECTION IN DEG. MAG.";
```

```
1910 INPUT W
1920 DISP "ENTER WIND VELOCITY IN KNOTS";
1930 INPUT S
1940 REM
1950 IF W=0 THEN 2040
1960 IF (ABS(W-R) >= 90) THEN 1990
1970 H=W-R
1980 GOTO 2050
1990 IF (W-R) >= 0 THEN 2020
2000 H=W-R+360
2010 GOTO 2050
2020 H=W-R-360
2030 GOTO 2050
2040 H=W
2050 I=S*COS((H)*(PI/180))
2060 J=S*SIN((H)*(PI/180))
2070 Q2=I
2080 I=FNA(I)
2090 Q3=J
2100 J=FNA(J)
2110 REM
2120 REM------------------------------------------------------------------------
2130 REM  CALCULATION OF TAKEOFF DISTANCE WITH WIND
2140 REM------------------------------------------------------------------------
2150 REM
2160 C0=E
2170 IF E>4257.1429 THEN 2210
2180 C1=+4.6399E+00-4.5821E-02*E+3.2832E-05*E↑2-1.1474E-08*E↑3+1.3457E-12*E↑4
2190 C2=-6.6592E-01+1.9513E-03*E-1.6041E-06*E↑2+5.4368E-10*E↑3-6.1997E-14*E↑4
2200 GOTO 2240
2210 C1=-2.1528E+03+1.3821E+00*E-3.2541E-04*E↑2+3.2638E-08*E↑3-1.189E-12*E↑4
2220 C2=+4.9049E+01-3.1663E-02*E+7.4167E-06*E↑2-7.4452E-10*E↑3+2.7181E-14*E↑4
2230 REM
2240 K=C0+C1*I+C2*I↑2
2250 REM
2260 REM------------------------------------------------------------------------
2270 REM    ESTABLISH TAKEOFF DISTANCE ROUND-OFF CRITERIA
2280 REM------------------------------------------------------------------------
```

```
2290 REM
2300 R0=0.25
2310 Y=100
2320 REM
2330 REM-----------------------------------------------------------------------
2340 REM CALCULATION AND COMPARISION OF T/O DIST. WITH T/O UNSAFE/NOT RECOM.DIST
2350 REM-----------------------------------------------------------------------
2360 REM
2370 Q4=E
2380 E=FNA(E)
2390 Q5=K
2400 K=FNA(K)
2410 F=1.0164E+04-6.4003E+02*D+8.1496E+01*D↑2-2.8303E+00*D↑3
2420 Q6=F
2430 F=FNA(F)
2440 G=9.977E+03-1.5271E+03*D+2.3768E+02*D↑2-1.0268E+01*D↑3
2450 Q7=G
2460 G=FNA(G)
2470 IF E >= F THEN 3140
2480 IF E >= G AND E<F THEN 3200
2490 GOTO 2680
2500 REM
2510 REM-----------------------------------------------------------------------
2520 REM ROUND-OFF CALCULATIONS
2530 REM-----------------------------------------------------------------------
2540 REM
2550 DEF FNA(X)
2560 V1=INT(X/Y)
2570 V=X/Y-INT(V1)
2580 IF V<R0 THEN 2610
2590 Z=(V1+1)*Y
2600 GOTO 2620
2610 Z=V1*Y
2620 RETURN Z
2630 REM
2640 REM-----------------------------------------------------------------------
2650 REM PRINT OUTPUT
2660 REM-----------------------------------------------------------------------
```

```
2670 REM
2680 PRINT
2690 PRINT "-----------------------------------------------------------------------
2700 PRINT "A0 =",A0
2710 PRINT "A1 =",A1,"INDEX =",D
2720 PRINT "A2 =",A2,"W/A =",H
2730 PRINT "B0 = ",B0,"T/OV =",Q1
2740 PRINT "B1 = ",B1,"H/TW =",Q2
2750 PRINT "B2 = ",B2,"CW =",Q3
2760 PRINT "B3 = ",B3,"NWT/O =",Q4
2770 PRINT "C0 =",C0,"WWT/O =",Q5
2780 PRINT "C1 =",C1,"T/OUS =",Q6
2790 PRINT "C2 =",C2,"T/ONR =",Q7
2800 PRINT "-----------------------------------------------------------------------
2810 PRINT
2820 PRINT "TAKEOFF GROSS WEIGHT =",A,"LBS."
2830 PRINT
2840 PRINT "RUNWAY PRESSURE ALTITUDE =",B,"FT."
2850 PRINT
2860 PRINT "RUNWAY TEMPERATURE =",C,"DEGREES (F)"
2870 PRINT
2880 PRINT "RUNWAY HEADING =",R,"DEG."
2890 PRINT
2900 PRINT "RUNWAY WINDS =",W,"DEG. AT",S,"KTS."
2910 PRINT
2920 IF ABS(H)>90 THEN 2950
2930 PRINT "HEADWIND =",I,"KTS."
2940 GOTO 2960
2950 PRINT "TAILWIND =",ABS(I),"KTS."
2960 PRINT
2970 IF H=0 THEN 3040
2980 IF H=180 THEN 3040
2990 IF H>0 AND H<180 THEN 3020
3000 PRINT "LEFT CROSSWIND =",ABS(J),"KTS."
3010 GOTO 3050
3020 PRINT "RIGHT CROSSWIND =",J,"KTS."
3030 GOTO 3050
3040 PRINT "CROSSWIND =",J,"KTS."
```

```
3050 PRINT
3060 PRINT "NO WIND TAKEOFF DISTANCE =",E,"FEET"
3070 PRINT
3080 PRINT "TAKEOFF DISTANCE WITH WIND =",K,"FEET"
3090 PRINT
3100 PRINT "TAKEOFF VELOCITY =",L,"KTS."
3110 PRINT
3120 PRINT "------------------------------------------------------------------"
3130 GOTO 3400
3140 PRINT
3150 PRINT "TAKEOFF UNSAFE!!!-T/O DISTANCE EXCEEDS",F,"FT. "
3160 PRINT
3170 PRINT "VERIFY CORRECT R/W TEMP.,R/W ALT.,GROSS WT. AND RE-COMPUTE T/O DIST.
3180 PRINT
3190 GOTO 2680
3200 PRINT
3210 PRINT "TAKEOFF NOT RECOMMENDED!--T/O DISTANCE EXCEEDS",G,"FT."
3220 PRINT
3230 PRINT "VERIFY CORRECT R/W TEMP.,R/W ALT.,GROSS WT. AND RE-COMPUTE T/O DIST.
3240 PRINT
3250 GOTO 2680
3260 PRINT
3270 PRINT "GROSS WT MUST BE >30000 AND <60000 : RE-ENTER CORRECT GROSS WT."
3280 PRINT
3290 GOTO 1070
3300 REM
3310 PRINT "PRESSURE MUST BE >=0 AND <=8000 FT. : RE-ENTER CORRECT P/A "
3320 PRINT
3330 GOTO 1460
3340 REM
3350 PRINT "AMBIENT TEMPERATURE MUST BE >=0 AND <=120 DEG.(F) : RE-ENTER DEG."
3360 PRINT
3370 GOTO 1560
3380 REM------------------------------------------------------------------
3390 REM
3400 GOTO 1070
3410 END
```

APPENDIX C

CRUISE PERFORMANCE PHASE CHARTS

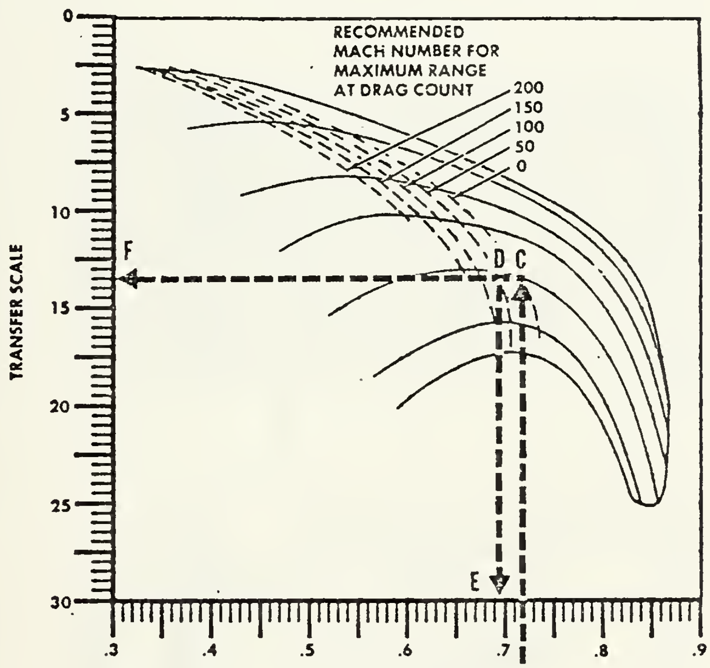
CRUISE PERFORMANCE

P-8 ENGINE

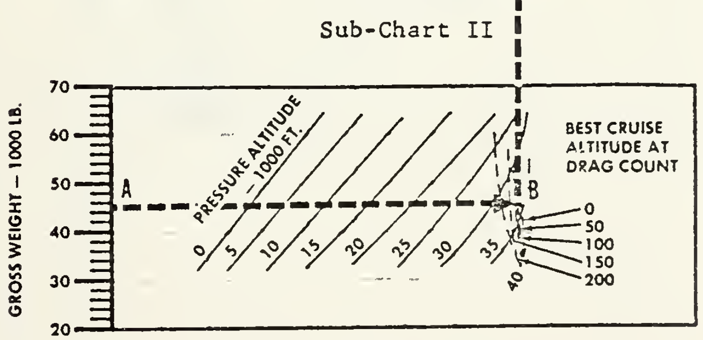
PHASE I — CLEAN AIRCRAFT TRANSFER SCALE

DATE 15 MARCH 1971
DATA BASIS: ESTIMATED

FUEL GRADE: JP-5
FUEL DENSITY: 6.8 LB./GAL.



Sub-Chart II



Sub-Chart I

ADF1-311

Figure 11-11

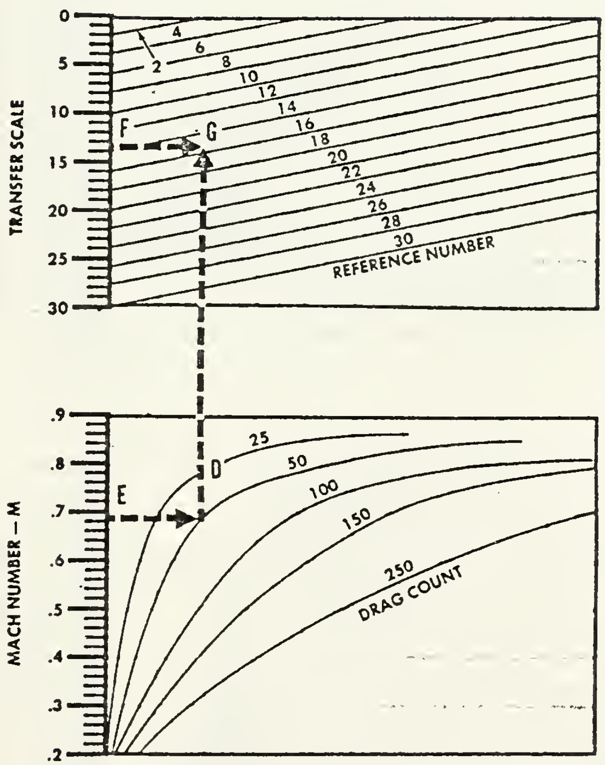
CRUISE PERFORMANCE

P-8 ENGINE

PHASE II — AIRCRAFT REFERENCE NUMBER

DATE 15 MARCH 1971
DATA BASIS: ESTIMATED

FUEL GRADE: JP-5
FUEL DENSITY: 6.8 LB./GAL.



ADF1-312

Figure 11-12

CRUISE PERFORMANCE

P-8 ENGINE

PHASE III — POUNDS OF FUEL PER NAUTICAL MILE

DATE 15 MARCH 1971
DATA BASIS: ESTIMATED

FUEL GRADE: JP-5
FUEL DENSITY: 6.8 LB./GAL.

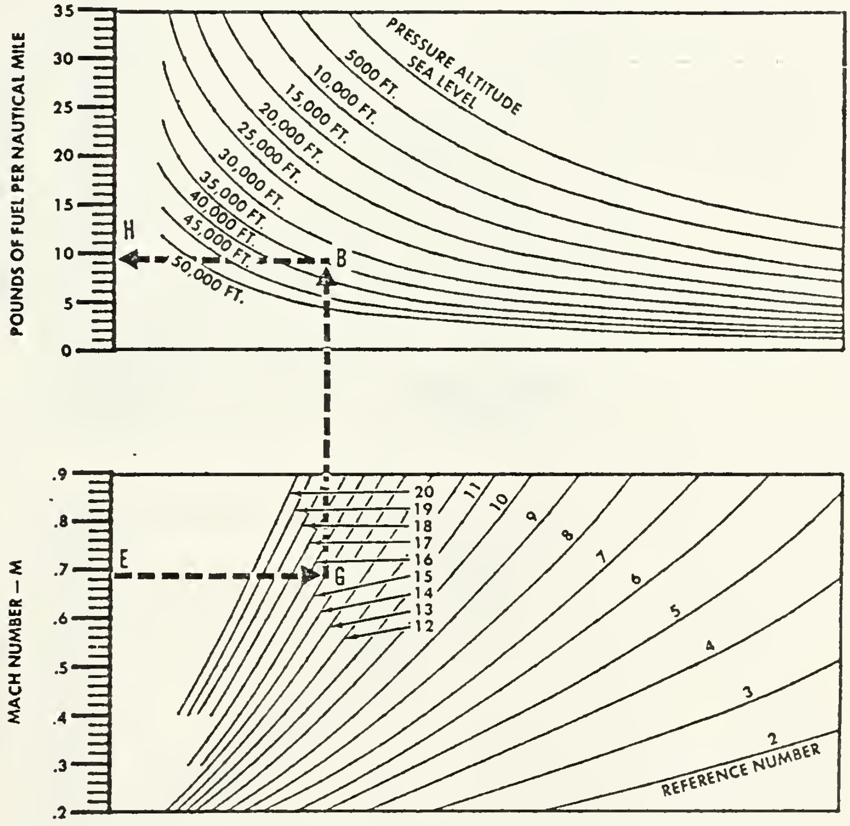


Figure 11-13

CRUISE PERFORMANCE

P-8 ENGINE

PHASE IV — FUEL FLOW

DATE 15 MARCH 1971
DATA BASIS: ESTIMATED

FUEL GRADE: JP-5
FUEL DENSITY: 6.8 LB./GAL.

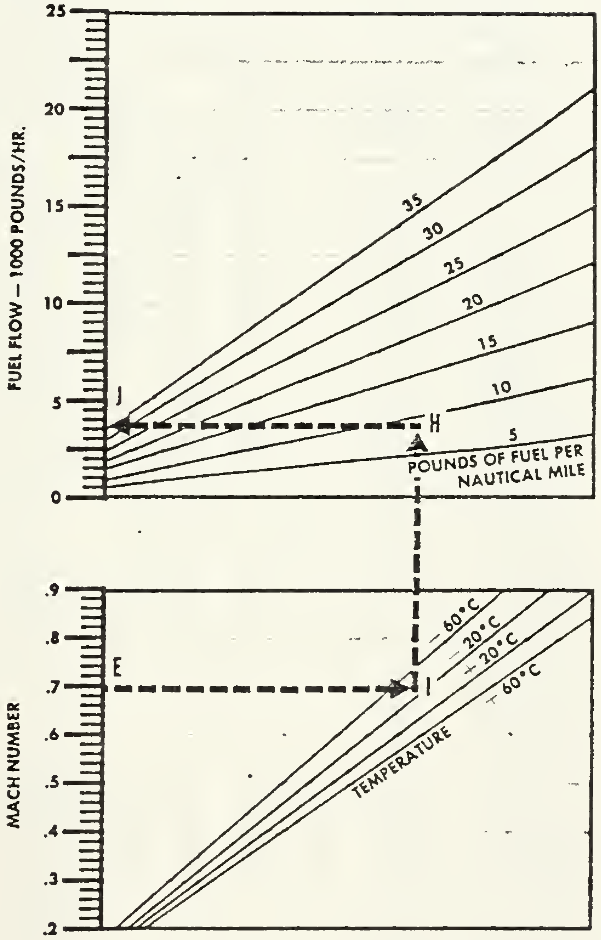


Figure 11-14

APPENDIX D

CRUISE PERFORMANCE COMPUTER PROGRAM

```
10 PRINT "*****************************************************************"
20 PRINT "*                                                               *"
30 PRINT "*          A-6E NATOPS CRUISE PERFORMANCE COMPUTER PROGRAM      *"
40 PRINT "*              PHASE I - CLEAN AIRCRAFT TRANSFER SCALE          *"
50 PRINT "*                                                               *"
60 PRINT "*     MAJOR J.D.RESTIVO, USMC         NAVAL POSTGRADUATE SCHOOL *"
70 PRINT "*                                            JUNE 1978          *"
80 PRINT "*****************************************************************"
90 PRINT
100 PRINT
110 PRINT "THE A-6E AIRCRAFT NATOPS CRUISE PERFORMANCE CHART WITH THE J-52-P8"
120 PRINT "ENGINE INSTALLED IS DIVIDED INTO FOUR PHASES OR FOUR SEPARATE CHARTS"
130 PRINT "THESE PHASES ARE:"
140 PRINT
150 PRINT "           PHASE-I     CLEAN AIRCRAFT TRANSFER SCALE"
160 PRINT
170 PRINT "           PHASE-II    AIRCRAFT REFERENCE NUMBER"
180 PRINT
190 PRINT "           PHASE-III   POUNDS OF FUEL PER NAUTICAL MILE"
200 PRINT
210 PRINT "           PHASE-IV    FUEL FLOW"
220 PRINT
230 PRINT "THE OUTPUT FROM EACH CHART IS CARRIED OVER AS INPUT TO THE NEXT"
240 PRINT "CHART,IN SEQUENCE,UNTIL ARRIVING AT THE FINAL OUTPUT OF ↑FUEL FLOW↑."
250 PRINT
260 PRINT "THIS PROGRAM ONLY COMPUTES PHASE-I OF CRUISE PERFORMANCE."
270 PRINT "THEREFORE, THE OUTPUT OF THIS PROGRAM, BEST CRUISE MACH AND  "
280 PRINT "TRANSFER SCALE, WHICH WOULD BE THE INPUT TO THE PHASE-II CHART "
290 PRINT "IS NOT ROUNDED-OFF FOR COCKPIT USE."
300 PRINT
310 PRINT "COMPUTER PROGRAMS FOR PHASES II,III,AND IV WOULD BE INTEGRATED"
320 PRINT "WITH THIS PROGRAM TO PROVIDE ONE COMPUTER PROGRAM WHICH WOULD"
330 PRINT "YEILD THE FINAL OUTPUT OF ↑FUEL FLOW↑ FOR THE INPUT PARAMETERS."
340 PRINT
350 PRINT "A LEGEND IS PROVIDED TO ASSIST IN INTERPRETATION OF THE PROGRAM"
360 PRINT "CALCULATIONS AND FOR SUBSEQUENT PHASE INTEGRATION."
370 PRINT
380 PRINT "-----------------------------------------------------------------"
```

```
390 PRINT
400 PRINT
410 PRINT "                              **** LEGEND ****"
420 PRINT
430 PRINT "          *INPUT VARIABLES*              *OUTPUT VARIABLES*"
440 PRINT
450 PRINT "        P = PRESSURE ALTITUDE        M = MACH NUMBER"
460 PRINT "        G = GROSS WEIGHT             T = TRANSFER SCALE"
470 PRINT "        D = DRAG COUNT"
480 PRINT
490 PRINT "                    *EQUATION CO-EFFICIENTS*"
500 PRINT
510 PRINT "               A0,A1,A2       = PRESSURE ALTITUDE"
520 PRINT "               B0,B1,B2       = GUIDE LINES"
530 PRINT "               C0,C1,C2,C3,C4 = DRAG COUNT"
540 PRINT
550 PRINT "                    *ITERATIVE CALCULATIONS*"
560 PRINT
570 PRINT "         T0 = INTIAL TRANSFER SCALE AT ZERO DRAG COUNT"
580 PRINT "         T1 = TRANSFER SCALE CALCULATED FROM GUIDE LINE EQUATIONS"
590 PRINT "         M0 = INITIAL MACH FROM PRESSURE ALTITUDE/GROSS WEIGHT"
600 PRINT "         M1 = MACH CALCULATED FROM DRAG COUNT EQUATIONS"
610 PRINT "         MD = LAST DECREMENTED MACH AFTER COMPARISON OF M0 & M1"
620 PRINT "                (EACH ITERATION DECREMENTS *M-.01*)"
630 PRINT "         M2 = FINAL CRUISE MACH AFTER SATISFACTORY COMPARISON"
640 PRINT "         M3 = FINAL COMPARISON BETWEEN M1 & MD"
650 PRINT
660 PRINT "-----------------------------------------------------------------"
670 PRINT
680 PRINT "NOW INPUT PRESSURE ALTITUDE,GROSS WEIGHT, AND DRAG COUNT AS"
690 PRINT "REQUESTED BY THE PROGRAM.. THIS PROGRAM IS RESTRICTED TO THE"
700 PRINT
710 PRINT "FOLLOWING A-6E NATOPS CRUISE PERFORMANCE CHART CABILITIES :"
720 PRINT
730 PRINT "      PRESSURE ALTITUDE ....   >=      0 AND <= 40,000 FT."
740 PRINT "      GROSS WEIGHT..........   >= 32,000 AND <= 60,400 LBS."
750 PRINT "      DRAG COUNT............   >=      0 AND <= 200"
760 PRINT
```

```
770 PRINT "INPUTS WHICH EXCEEDS THESE LIMITS OR AN ACCEPTABLE COMBINATION"
780 PRINT "OF THE INPUT VARIABLES WILL BE REJECTED BY THE PROGRAM"
790 PRINT
800 PRINT "*****************************************************************************"
810 REM
820 REM----------------------------------------------------------------------------
830 REM NATOPS CHART PRESSURE ALTITUDE LIMITATION VERIFICATION
840 REM----------------------------------------------------------------------------
850 REM
860 DISP "ENTER PRESSURE ALTITUDE";
870 INPUT P
880 REM
890 IF P >= 0 AND P <= 40000 THEN 1000
900 REM
910 PRINT "PRESSURE ALTITUDE =";P"FT.";"WHICH EXCEEDS NATOPS CHART CAPABILITY "
920 PRINT "RE-ENTER PRESSURE ALTITUDE WHICH IS >= 0 AND <=40000 FT."
930 PRINT " "
940 GOTO 2780
950 REM
960 REM----------------------------------------------------------------------------
970 REM  DETERMINATION OF PRESSURE ALTITUDE EQUATIONS
980 REM----------------------------------------------------------------------------
990 REM
1000 IF P >= 30000 THEN 1140
1010 REM
1020 I0=+2.6225E-01-3.7238E-05*P+1.4312E-08*P↑2-1.8518E-12*P↑3+1.0981E-16*P↑4
1030 J0=-3.0063E-21*P↑5+3.0843E-26*P↑6
1040 A0=I0+J0
1050 I1=+3.9658E-06+1.7782E-09*P-6.0298E-13*P↑2+8.07831E-17*P↑3-4.9189E-21*P↑4
1060 J1=+1.3809E-25*P↑5-1.4511E-30*P↑6
1070 A1=I1+J1
1080 I2=-5.5004E-14-1.7573E-14*P+6.2437E-18*P↑2-8.5511E-22*P↑3+5.3198E-26*P↑4
1090 J2=-1.5262E-30*P↑5+1.6358E-35*P↑6
1100 A2=I2+J2
1110 REM
1120 GOTO 1170
1130 REM
1140 A0=+4.6921E+00-2.7056E-04*P+4.2601E-09*P↑2
```

```
1150 A1=-2.4607E-04+1.5524E-08*P-2.3373E-13*P↑2
1160 A2=+3.1544E-09-1.9328E-13*P+2.8624E-18*P↑2
1170 REM
1180 REM---------------------------------------------------------------------------
1190 REM  NATOPS CHART GROSS WEIGHT LIMITATION VERIFICATION
1200 REM---------------------------------------------------------------------------
1210 REM
1220 DISP "ENTER GROSS WEIGHT";
1230 INPUT G
1240 REM
1250 IF G >= 32000 AND G <= 60400 THEN 1370
1260 REM
1270 PRINT "GROSS WEIGHT =",G"LBS.","WHICH EXCEEDS NATOPS CHART CAPABILITY"
1280 PRINT "RE-ENTER GROSS WEIGHT WHICH IS >= 32,000 AND <= 60,400 LBS."
1290 PRINT " "
1300 REM
1310 GOTO 1220
1320 REM
1330 REM---------------------------------------------------------------------------
1340 REM  INTIAL MACH CALCULATION
1350 REM---------------------------------------------------------------------------
1360 REM
1370 M0=A0+A1*G+A2*G↑2
1380 REM
1390 REM---------------------------------------------------------------------------
1400 REM  INTIAL MACH NATOPS CHART LIMTATION VERIFICATION
1410 REM---------------------------------------------------------------------------
1420 REM
1430 IF M0 <= 0.7344 THEN 1520
1440 REM
1450 PRINT "INTIAL MACH =",M0
1460 PRINT "INTIAL MACH EXCEEDS NATOPS CHART CAPABILITY OF M0 = .7344"
1470 PRINT "GROSS WEIGHT/PRESSURE ALTITUDE COMBINATION IS UNACCEPTABLE"
1480 PRINT "REDUCE ONE OF THE VARIABLES AND RE-ENTER"
1490 PRINT ""
1500 REM
1510 GOTO 2780
1520 REM
```

```
1530 REM-----------------------------------------------------------------------
1540 REM  DRAG COUNT NATOPS CHART LIMITATION VERIFICATION
1550 REM-----------------------------------------------------------------------
1560 REM
1570 DISP "ENTER DRAG COUNT";
1580 INPUT D
1590 REM
1600 IF D >= 0 AND D <= 200 THEN 1680
1610 PRINT " "
1620 PRINT "DRAG COUNT =",D"WHICH EXCEEDS NATOPS CAPABILITY"
1630 PRINT "RE-ENTER DRAG COUNT WHICH IS >= 0 AND <= 200"
1640 PRINT " "
1650 REM
1660 GOTO 1570
1670 REM
1680 IF D <= 100 THEN 1870
1690 REM
1700 M9=+7.066E-01+7.14E-04*D-4.36E-06*D↑2
1710 REM
1720 IF M0 <= M9 THEN 1870
1730 REM
1740 PRINT "LIMIT MACH =",M9
1750 PRINT "DRAG COUNT EXCEEDS NATOPS CHART CAPABILITY"
1760 PRINT "FOR INITIAL CRUISE MACH OF",M0
1770 PRINT "ALTITUDE/GROSS WEIGHT/DRAG COUNT COMBINATION IS UNACCEPTABLE"
1780 PRINT " REDUCE ONE OF THE VARIABLES AND RE-ENTER"
1790 PRINT " "
1800 REM
1810 GOTO 2780
1820 REM
1830 REM-----------------------------------------------------------------------
1840 REM   DETERMINATION OF INTITIAL TRANSFER SCALE
1850 REM-----------------------------------------------------------------------
1860 REM
1870 M=M0
1880 IF M<0.7156 THEN 1920
1890 REM
1900 T0=+2.1847E+03-6.1251E+03*M+4.3194E+03*M↑2
```

```
1910 GOTO 1980
1920 T0=+6.7716E+01-5.6168E+02*M+1.7414E+03*M↑2-2.3221E+03*M↑3+1.1705E+03*M↑4
1930 REM
1940 REM-----------------------------------------------------------------------
1950 REM  DETERMINATION OF GUIDE LINE EQUATION
1960 REM-----------------------------------------------------------------------
1970 REM
1980 T=T0
1990 IF T<10.7813 THEN 2070
2000 REM
2010 B0=+1.6841E+03-3.6941E+02*T+2.6714E+01*T↑2-6.0776E-01*T↑3
2020 B1=-4.6471E+03+1.0163E+03*T-7.3273E+01*T↑2+1.6687E+00*T↑3
2030 B2=+3.2228E+03-6.9912E+02*T+5.0299E+01*T↑2-1.1452E+00*T↑3
2040 REM
2050 GOTO 2150
2060 REM
2070 B0=-7.9259E+01+4.2925E+01*T-6.4083E+00*T↑2+3.2418E-01*T↑3
2080 B1=+3.2564E+02-1.7001E+02*T+2.5045E+01*T↑2-1.2128E+00*T↑3
2090 B2=-3.3729E+02+1.7587E+02*T-2.5326E+01*T↑2+1.1824E+00*T↑3
2100 REM
2110 REM-----------------------------------------------------------------------
2120 REM  TRANSFER SCALE CALCULATION (T1)
2130 REM-----------------------------------------------------------------------
2140 REM
2150 T1=B0+B1*M+B2*M↑2
2160 REM
2170 REM-----------------------------------------------------------------------
2180 REM  DETERMINATION OF DRAG COUNT EQUATION
2190 REM-----------------------------------------------------------------------
2200 REM
2210 IF M<M0 THEN 2330
2220 REM
2230 C0=+2.0599E-01-1.0433E-03*D-2.5084E-07*D↑2+7.2607E-08*D↑3-2.7727E-10*D↑4
2240 C1=+7.3033E-02+3.3437E-04*D-7.7116E-08*D↑2-3.2974E-08*D↑3+1.4509E-10*D↑4
2250 C2=-3.1934E-03-4.5034E-05*D-2.5791E-07*D↑2+8.4545E-09*D↑3-3.6759E-11*D↑4
2260 C3=+3.9357E-05+1.7202E-06*D+6.2337E-08*D↑2-1.0897E-09*D↑3+4.4301E-12*D↑4
2270 C4=+2.4598E-07+1.0275E-08*D-3.5327E-09*D↑2+4.9978E-11*D↑3-1.9204E-13*D↑4
2280 REM
```

```
2290 REM-----------------------------------------------------------------------
2300 REM  MACH CALCULATION (M1)
2310 REM-----------------------------------------------------------------------
2320 REM
2330 T=T1
2340 M1=C0+C1*T+C2*T↑2+C3*T↑3+C4*T↑4
2350 REM
2360 REM-----------------------------------------------------------------------
2370 REM  COMPARISION AND DECREMATION OF CALCULATED MACH AND INITIAL MACH
2380 REM-----------------------------------------------------------------------
2390 REM
2400 IF ABS(M-M1) <= 0.01 THEN 2500
2410 REM
2420 M=M-0.01
2430 REM
2440 GOTO 2150
2450 REM
2460 REM-----------------------------------------------------------------------
2470 REM  PRINT OUTPUT
2480 REM-----------------------------------------------------------------------
2490 REM
2500 M2=(M1+M)/2
2510 M3=M1-M
2520 REM
2530 PRINT "-------------------------------------------------------------------
2540 PRINT "A0 =",A0
2550 PRINT "A1 =",A1"T0 =",T0
2560 PRINT "A2 =",A2"T1 =",T1
2570 PRINT "B0 =",B0"M0 =",M0
2580 PRINT "B1 =",B1"M1 =",M1
2590 PRINT "B2 =",B2"MD =",M
2600 PRINT "C0 =",C0"M2 =",M2
2610 PRINT "C1 =",C1"M3 =",M3
2620 PRINT "C2 =",C2"DC =",D
2630 PRINT "C3 =",C3
2640 PRINT "C4 =",C4
2650 PRINT "-------------------------------------------------------------------
2660 PRINT
```

```
2670 PRINT "THE FOLLOWING VALUES WILL BE TRANSFERED TO PHASE II-CHART "
2680 PRINT
2690 PRINT "PRESSURE ALTITUDE =",P
2700 PRINT "GROSS WEIGHT =",G
2710 PRINT "DRAG COUNT =",D
2720 PRINT "CRUISE MACH =",M2
2730 PRINT "TRANSFER SCALE =",T
2740 PRINT
2750 PRINT "--------------------------------------------------------------------
2760 PRINT
2770 REM
2780 GOTO 860
2790 END
```

APPENDIX E

SAMPLE PROGRAM RESULTS

1. Take-off Performance

```
--------------------------------------------------------------------------------
A0 =          3.45000E-04
A1 =          0.025009       INDEX =        1.8183042
A2 =          8.81720E-05    W/A =          42
B0 =          2376.438977    T/OV =         140.1292314
B1 =          452.064        H/TW =         14.8628965
B2 =          21.0168        CW =           13.38261213
B3 =          4.192736       NWT/O =        3293.12083
C0 =          3293.12083     WWT/O =        2777.553036
C1 =         -41.70780002    T/OUS =        9252.66029
C2 =          0.489107578    T/ONR =        7924.363975
--------------------------------------------------------------------------------

TAKEOFF GROSS WEIGHT =             48000          LBS.

RUNWAY PRESSURE ALTITUDE =         0              FT.

RUNWAY TEMPERATURE =               60             DEGREES (F)

RUNWAY HEADING =                   360            DEG.

RUNWAY WINDS =  42              DEG. AT           20              KTS.

HEADWIND =      15              KTS.

RIGHT CROSSWIND =                  13             KTS.

NO WIND TAKEOFF DISTANCE =         3300           FEET

TAKEOFF DISTANCE WITH WIND =       2800           FEET

TAKEOFF VELOCITY =                 140            KTS.

--------------------------------------------------------------------------------
```

2. Cruise Performance

```
---------------------------------------------------------------------
A0 =          0.4028689
A1 =          1.16900E-05   T0 =        13.64705179
A2 =         -1.06686E-10   T1 =        13.64602006
B0 =          73.29603335   M0 =        0.718184874
B1 =         -182.854075    M1 =        0.709534425
B2 =          138.9578805   MD =        0.718184874
C0 =          0.185560157   M2 =        0.713859650
C1 =          0.079448976   M3 =       -8.65045E-03
C2 =         -4.13549E-03   DC =        20
C3 =          9.06870E-05
C4 =         -5.92502E-07
---------------------------------------------------------------------

THE FOLLOWING VALUES WILL BE TRANSFERED TO PHASE II-CHART

PRESSURE ALTITUDE =              33000
GROSS WEIGHT =  48000
DRAG COUNT =    20
CRUISE MACH =   0.713859650
TRANSFER SCALE =                 13.64602006

---------------------------------------------------------------------
```

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